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Development of a Linac Vault Shielding Calculation Tool

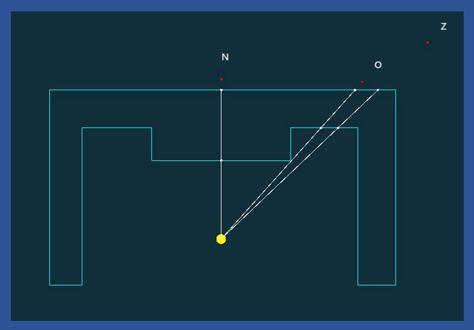
Reddy H. Ma[1]; Ynuzhi Ma[2], Sigen Wang, PhD[3]
[1]Cary Grove High school, Cary IL; [2]Northwestern Medicine McHenry Hospital; [3]Saint Alphonsus Cancer Institute, Boise ID

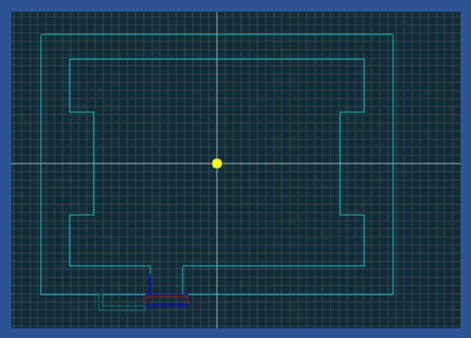
ABSTRACT

This work presents the development of a standalone application that performs NCRP 151-based LINAC shielding calculations using two-dimensional (2D) vault structure modeling tool combined with a raytracing–based computational framework.

The application was developed to calculate shielding requirements for primary barriers, secondary barriers, ceilings, mazes, and doors. User inputs include vault dimensions, LINAC workload, beam energy, use and occupancy factors, and shielding materials such as concrete, steel, and lead. Vault geometry is represented with three 2D plots in the three cardinal planes.

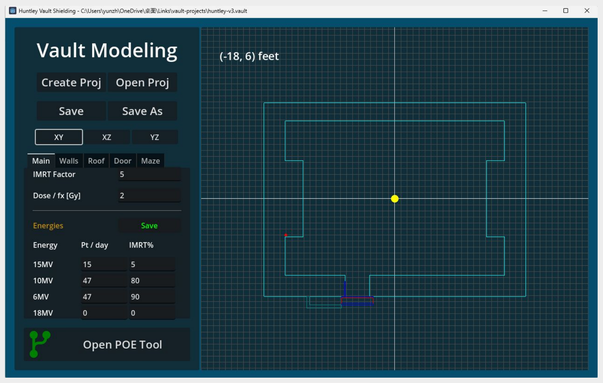
A ray-tracing algorithm propagates radiation paths from the source LINAC head to standard NCRP reference points as well as user-defined locations. Each ray is segmented by intersected shielding materials, and cumulative attenuation and resulting dose are computed along the path.

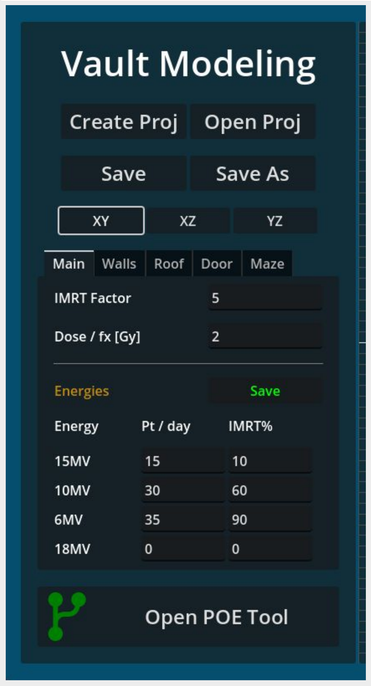




INTRODUCTION

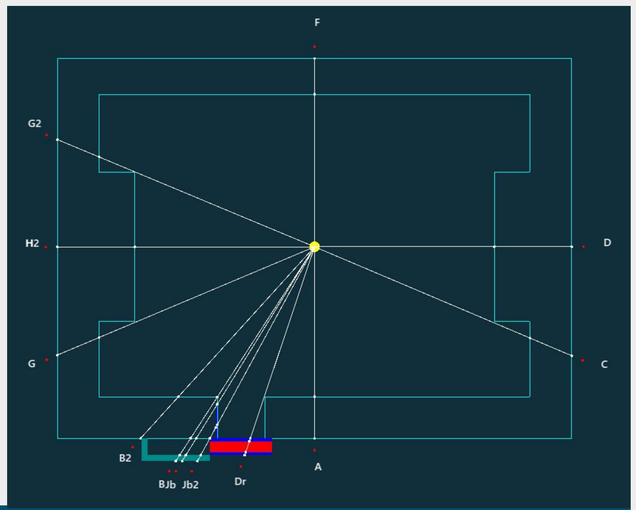
Shielding design for medical linear accelerator (LINAC) vaults is commonly performed using spreadsheet-based implementations of NCRP Report No. 151. While effective, these approaches are limited by fixed calculation points and restricted geometric flexibility. This work presents the development of a standalone application that performs NCRP-based LINAC shielding calculations using two-dimensional (2D) vault modeling combined with a ray-tracing–based computational framework.

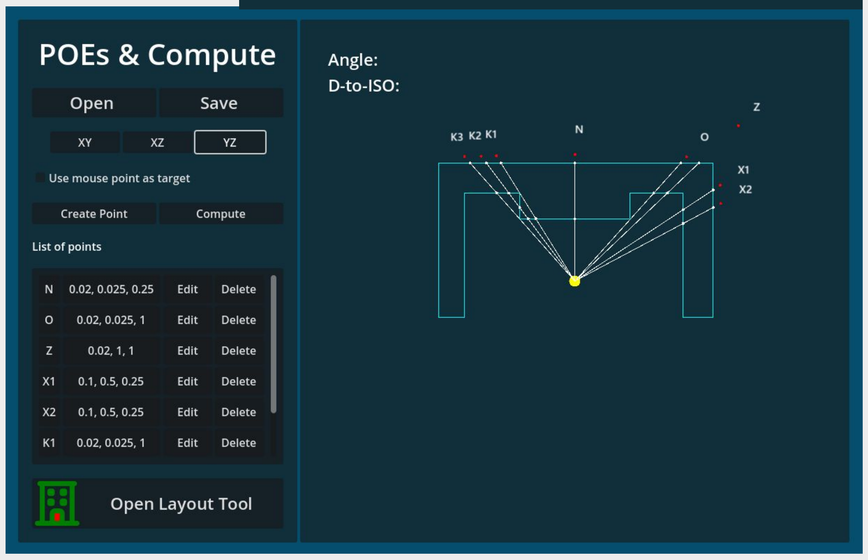




RESULTS

For standard vault configurations, calculated shielding thicknesses and dose estimates were consistent with conventional spreadsheet-based NCRP 151 calculations. The 2D ray-tracing framework enabled flexible evaluation of shielding performance at arbitrary locations within each cardinal plane and supported mixed material barriers and non-standard geometries that are difficult to evaluate using spreadsheet methods alone. The application was verified by comparison with our spreadsheet-based hand calculations. All key points are within 1% differences.





DISCUSSION

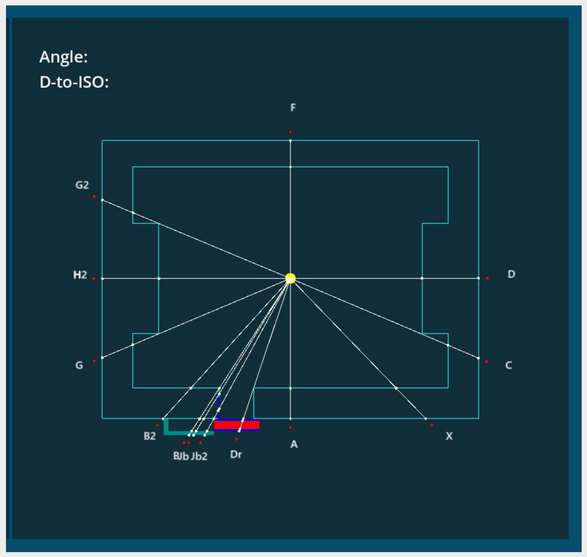
The novelty of this work is the integration of established NCRP Report No. 151 shielding methodology with a two-dimensional, ray-tracing–based computational framework within a standalone application. Unlike traditional spreadsheet-based approaches limited to fixed reference points, this tool enables geometry-aware evaluation of radiation attenuation at user-defined locations across the cardinal planes and supports mixed material barriers and non-standard vault geometries. This approach enhances flexibility, transparency, constancy, and spatial insight in LINAC shielding analysis while remaining fully consistent with current clinical shielding standards.

```
#### Point D  -  primary  -  West wall primary - pathway / parking
#### P=0.02 [mSv/wk], T=0.025, U=0.25, SLANT=0.0 [deg], d2iso=6.90 [m]
>>> En=15MV, W=150.0 [Gy/wk]
mat=  concrete, attenu=1.742E-05, t=1.98 [m], TVL1=0.44 [m], TVLe=0.41 [m]
==============================
 En  | Unshielded |  Shielded
-----+------------+------------
15MV |    601.459 |      0.010  mSv/wk
==============================
>>> En=10MV, W=300.0 [Gy/wk]
mat=  concrete, attenu=5.669E-06, t=1.98 [m], TVL1=0.41 [m], TVLe=0.37 [m]
==============================
 En  | Unshielded |  Shielded
-----+------------+------------
10MV |   1202.918 |      0.007  mSv/wk
==============================
>>> En= 6MV, W=350.0 [Gy/wk]
mat=  concrete, attenu=1.311E-06, t=1.98 [m], TVL1=0.37 [m], TVLe=0.33 [m]
==============================
 En  | Unshielded |  Shielded
-----+------------+------------
 6MV |   1403.404 |      0.002  mSv/wk
==============================

 Total shielded dose =  1.913E-02 [mSv/wk]
 Smaller than P/T? Yes
 Smaller than 1/2 of P/T? Yes
```

```
#### Point C  -  secondary  -  W wall secondary - pathway
#### P=0.02 [mSv/wk], T=0.025, U=0.25, SLANT=23.0 [deg], d2iso=7.46 [m]
>>> En=15MV, W=150.0 [Gy/wk], WL=210.0 [Gy/wk]
LK: En=15MV, att=3.803E-04,                concrete, t=1.16 [m], TVL1=0.36 [m], TVLe=0.33 [m]
PS: En=15MV, att=1.744E-03,                concrete, t=1.16 [m], TVL=0.42 [m]
Nn: En=15MV, att=3.231E-06,                concrete, t=1.16 [m], TVL=0.211 [m]
==========================================
 En  |  PScatter  |  Leakage   | Neutron LK
-----+------------+------------+-----------
15MV |    14.5165 |     3.7705 |     2.6394  mSv/wk     <-- Unshield
15MV |     0.0253 |     0.0014 |     0.0000  mSv/wk     <-- Shielded
==========================================
>>> En=10MV, W=300.0 [Gy/wk], WL=1020.0 [Gy/wk]
LK: En=10MV, att=2.465E-04,                concrete, t=1.16 [m], TVL1=0.35 [m], TVLe=0.31 [m]
PS: En=10MV, att=1.070E-03,                concrete, t=1.16 [m], TVL=0.39 [m]
Nn: En=10MV, att=3.231E-06,                concrete, t=1.16 [m], TVL=0.211 [m]
==========================================
 En  |  PScatter  |  Leakage   | Neutron LK
-----+------------+------------+-----------
10MV |    31.1876 |    18.3140 |     0.7326  mSv/wk     <-- Unshield
10MV |     0.0334 |     0.0045 |     0.0000  mSv/wk     <-- Shielded
==========================================
>>> En= 6MV, W=350.0 [Gy/wk], WL=1610.0 [Gy/wk]
LK: En= 6MV, att=1.505E-04,                concrete, t=1.16 [m], TVL1=0.34 [m], TVLe=0.29 [m]
PS: En= 6MV, att=3.913E-04,                concrete, t=1.16 [m], TVL=0.34 [m]
Nn: En= 6MV, att=3.231E-06,                concrete, t=1.16 [m], TVL=0.211 [m]
==========================================
 En  |  PScatter  |  Leakage   | Neutron LK
-----+------------+------------+-----------
 6MV |    42.2927 |    28.9073 |     0.0000  mSv/wk     <-- Unshield
 6MV |     0.0165 |     0.0043 |     0.0000  mSv/wk     <-- Shielded
==========================================

 Total shielded dose =  8.555E-02 [mSv/wk]
 Smaller than P/T? Yes
 Smaller than 1/2 of P/T? Yes
```

METHODS AND MATERIALS

A standalone software application was developed to calculate shielding requirements for primary barriers, secondary barriers, ceilings, mazes, and doors. User inputs include vault dimensions, LINAC workload, beam energy, use and occupancy factors, and shielding materials such as concrete, steel, and lead. Vault geometry is represented in 2D across the three cardinal planes. A ray-tracing algorithm propagates radiation paths from the source LINAC head to standard NCRP reference points as well as user-defined locations. Each ray is segmented by intersected shielding materials, and cumulative attenuation and resulting dose are computed along the path.



This standalone application enhances traditional NCRP-based LINAC shielding calculations by integrating 2D geometric modeling and ray tracing, enabling more flexible and spatially resolved analysis while maintaining consistency with established methodology. Extension to full three-dimensional vault modeling is currently under development.

REFERENCES

1. Report No. 151 , NCRP National council of radiation protection and measurements. 2005. Bethesda, Maryland
2. Shielding techniques for radiation oncology facilities, 2nd edition, Patton H. McGinley. 2002 Medical Physics Publishing, Madison, Wisconsin

CONTACT

Sigen Wang, PhD, DABR
Saint Alphonsus Cancer Institute
Boise ID 83706
sgwang88@yahoo.com

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